An Engineering Study of Onboard Checkout Techniques

A GUIDE TO ONBOARD CHECKOUT
VOLUME VI: STRUCTURES/MECHANICAL

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A GUIDE TO ONBOARD CHECKOUT
VOLUME VI: STRUCTURES/MECHANICAL

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FOREWORD

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I	71W-00308	Guidance, Navigation and Control
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III	71W-00310	Electrical Power
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V	71W-00312	Data Management
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This set of guides was prepared from the results of a nine month "Engineering Study of Onboard Checkout Techniques" (NAS9-11189) performed under NASA contract by the IBM Federal Systems Division at its Space Systems facility in Huntsville, Alabama, with the support of the McDonnell Douglas Astronautics Company Western Division, Huntington Beach, California.

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Section 1

INTRODUCTION

1.1 OBJECTIVE

With the advent of large scale aerospace systems, designers have recognized the importance of specifying and meeting design requirements additional to the classical functional and environmental requirements. These "additional" requirements include producibility, safety, reliability, quality, and maintainability. These criteria have been identified, grown into prominence, and become disciplines in their own right. Presently, it is inconceivable that any aerospace system/ equipment design requirements would be formulated without consideration of these criteria.

The complexity, sophistication and duration of future manned space missions demand that still another criterion needs to be considered in the formulation of system/equipment requirements. The concept of "checkoutability" denotes the adaptability of a system, subsystem, or equipment to a controlled checkout process. As with other requirements, it should also apply from the time of early design concept formulation.

The results of "An Engineering Study of Onboard Checkout Techniques" and other studies indicate that for an extended space mission onboard checkout is mandatory and applicable to all subsystems of the space system. In order to use it effectively, "checkoutability" should be incorporated into the design of each subsystem, beginning with initial performance requirements.

Conferences with researchers, system engineers and subsystem specialists in the course of the basic Onboard Checkout Techniques Study revealed an extensive interest in the idea of autonomous onboard checkout. Designers are motivated to incorporate "checkoutability" into their subsystem designs but express a need for information and guidance that will enable them to do so efficiently.

It is the objective of this report to present the results of the basic study as they relate to one space subsystem to serve as a guide, by example, to those who in the future need to implement onboard checkout in a similar subsystem. It is not practicable to formulate a firm set of instructions or recipes, because operational requirements, which vary widely among systems, normally determine the checkout philosophy. It is suggested that the reader study this report as a basis from which to build his own approach to "checkoutability."

1.2 BASIC STUDY SUMMARY

1.2.1 STUDY OBJECTIVE

The basic study was aimed at identification and evaluation of techniques for achieving the following capabilities in the operational Space Station/Base, under control of the Data Management System (DMS), with minimal crew intervention.

- Automated failure prediction and detection
- Automated fault isolation
- Failure correction
- Onboard electronic maintenance

1.2.2 STUDY BASELINE

The study started in July 1970. The system design baseline was established by the Space Station Phase B study results as achieved by the McDonnell-Douglas/IBM team, modified in accordance with technical direction from NASA-MSC. The overall system configuration was the 33-foot diameter, four-deck, 12-man station. Individual subsystem baseline descriptions are given in their respective "Guide to Onboard Checkout" reports.

1.2.3 STUDY TASKS

The basic study comprised five tasks. Primary emphasis was given to Task 1, Requirements Analysis and Concepts. This task established subsystem baseline descriptions and then analyzed them to determine their reliability/maintainability characteristics (criticality, failure modes and effects, maintenance concepts and line replaceable unit (LRU) definitions), checkout strategies, test definitions, and definitions of stimuli and measurements. After software preliminary designs were available, an analysis of checkout requirements on the DMS was performed.

A software task was performed to determine the software requirements dictated by the results of Task 1.

Task 3 was a study of onboard electronic maintenance requirements and recommendations of concepts to satisfy them. Supporting research and technology tasks leading to an onboard maintenance capability were identified. The study implementation plan and recommendations for implementing results of the study were developed in Task 4. The task final report also summarizes results of the study in all technical tasks.

Reliability, Task 5, was very limited in scope, resulting in an analysis of failure modes and effects in three Space Station subsystems, GN&C, DMS (computer group) and RF communications.

1.2.4 PREVIOUS REPORTS

Results of the basic study were reported by task in the following reports, under the general title of "An Engineering Study of Onboard Checkout Techniques, Final Report."

IBM Number	Title
71W-00111	Task 1: Requirements Analysis and Concepts
71W-00112	Task 2: Software
71W-00113	Task 3: Onboard Maintenance
71W-00114	Task 4: Summary and Recommendations
71W-00115	Task 5: Subsystem Level Failure Modes and Effects

Section 2

BASELINE SUBSYSTEM DESCRIPTIONS

2.1 GENERAL

This section describes the baseline Structures and Mechanical Subsystem which was analyzed to define onboard checkout requirements. In order to assess requirements for onboard checkout, descriptions at the subsystem level and the assembly level are required, as well as the major interfaces between subsystems.

The assembly level description for each of the subsystems (MSFC-DRL-160, Line Item 13) provided the primary working document for subsystem analysis. To reduce documentation, these documents have been incorporated by reference into this report, where applicable. Therefore, where no significant differences exist from the Phase B definition, this report contains a brief subsystem description and an identification of the referenced document containing the assembly level descriptions for that subsystem. Where significant differences do exist, the subsystem level description includes these changes in as much detail as is available. MSFC-DRL-160, Line Item 19, provided the major subsystem interface descriptions for analysis of integrated test requirements.

2.2 SYSTEM LEVEL DESCRIPTION

The Space Station structure consists primarily of four subsystem areas which will require checkout support. They are:

- Basic Structure
- Docking Mechanisms
- Spacecraft Access
  - Hatches
  - Airlocks
  - View Ports
- Antenna Deployment Mechanisms

2.2.1 BASIC STRUCTURE

The basic Space Station structure provides the necessary pressurized habitat, equipment support, meteoroid protection, radiators, insulation, and docking interfaces. Attainment of the required volume for the accommodation of crew, experiments, and subsystems within a 110,000-pound weight limit demands that the structure design be optimized. The structure must also have adequate factors of safety to satisfy the long life (ten years) requirements. The design uses state-of-the-art materials, design, and fabrication techniques.

The external cylindrical pressure shell and the center tunnel structure are 2219 aluminum alloy with integrally machined waffle stiffeners on the external shell and integral stabilizing rings on the tunnel. Each two-deck module is closed at each end with a toroidal dome membrane. The equipment in each module is supported by the deck structure located halfway between the domes. The deck is formed by a radial array of beams extending from the center tunnel to the external pressure shell. The thrust loads in the center tunnel structure are carried to the external pressure shell structure through a conic structure at the forward end of the station.

ECS radiator, thermal insulation, meteoroid protection, and a pressure shell are integrated into a 4.5 inch thick sandwich design. The external surface of 0.020-inch beaded aluminum sheet serves the dual function of being both the primary meteoroid bumper and the radiating surface for the ECS radiator. An inner, 0.010-inch corrugated aluminum sheet provides additional meteoroid protection and limits insulation blanket damage over the 10-year life. The two bumpers are supported by 1 section aluminum extrusions which contain dual passages for the ECS radiator fluid. The 0.110-inch, waffle stiffened pressure shell forms the interior surface of the sandwich. Tests of this design at the MDAC light gas gun facility have indicated that the no meteoroid puncture probability of the pressure shell is 0.985 for ten years.

2.2.2 DOCKING MECHANISM

The docking mechanism accomplishes the physical alignment of the vehicles, attenuates the relative closing velocities, and captures and rigidizes the two vehicles. In addition to the mating of the two vehicles, the system must accomplish the disconnection, detachment, and separation of the spacecraft from the Space Station.

The conceptual design prepared for the docking mechanism and shock absorber/actuator is described as follows. A gas spring is used for energy absorption so that the pressure can be varied to accommodate wide variations in the masses of the vehicles to be docked. A floating piston separates the gas from a low temperature hydraulic fluid. As the shock absorber strokes, the hydraulic fluid flows through a one-way valve and drives the floating piston down the shock absorber, doing work against the gas pressure. When the compression stroke is completed, the one-way valve prevents the shock absorber from springing back. A small bypass orifice permits it to return at a slow, controlled rate to its initial extended length. The gas spring pressure can then be reduced for retracting the frame to the stowed position.

2.2.3 ACCESS HATCHES, AIRLOCKS, VIEW PORTS

In the evolution of the Space Station configuration, the requirement for crew access to the various compartments, docked modules, external portions of the station, and consideration of redundant transfer paths in case of emergencies is essential for crew safety considerations. While normal crew activities and access to experiment and cargo modules will be accomplished in a shirtsleeve environment, some contingency operations will require pressure suit and airlock transfer capabilities.

The requirement for two separately pressurized volumes has been provided by the two-deck, common module design approach; in addition, the 10-foot-diameter center tunnel provides a third pressure volume. The expendables compartment is normally unpressurized except for shirtsleeve access for maintenance and repair. The forward portion of the center tunnel can be used as an airlock if necessary.

Each deck will have a 5-foot-diameter clear opening access hatch into the tunnel. These hatches will be open for the normal traffic flow, but, in cases of emergency, may be closed and sealed against fire, contamination, or depressurization in one of the common modules. If one of the common modules is depressurized, the tunnel environment will be referenced to the other common module environmental control system. Using pressure suits, the crew may then reenter the depressurized module for inspection and repair through the fixed airlock. This airlock will also permit access to the outside of the Space Station from either of the common modules for normal EVA activities.

2.2.4 ANTENNA DEPLOYMENT MECHANISM

The Space Station requires four 15-foot diameter communications antennas to provide high-gain RF acquisition and continuous tracking of relay satellites. These antennas are stowed during launch under the nose fairing together with the artificial-g telescoping spoke. Upon reaching orbit and ejection of fairings, the antenna mounting booms shall be extended and locked in operating position until artificial gravity operation. The antenna mounting boom requires the capability of being retracted and locked in a low inertia position during the artificial gravity mode. The antenna shall have a two-axis gimbal positioner located at the antenna end of the mounting boom. The azimuth axis shall be parallel to the Space Station Z axis. Each antenna shall be capable of scanning 360 degrees in azimuth and from +75 degrees to -10 degrees in elevation. During maintenance, the antennas shall be retracted to air lock ports where the back side of the antenna is accessible to intervehicular astronauts. The antenna locations shall be 45 degrees off the major Y-Z axes. The antenna masts are fixed length and actuated by an electric motor drive train located at the hinge line. Flexible power and signal leads must be provided at the hinge to provide power to the antenna drive and to transmit position signals. In addition, a swivel type waveguide must be provided at the mast hinge line.

2.3 ASSEMBLY LEVEL DESCRIPTIONS

Space Station MSFC-DRL-160, Line Item 8, Volume V, Book Mechanical, contains a description of the mechanical subsystem elements sufficiently detailed for checkout requirements analysis purposes and will become the primary working document for this purpose. MSFC-DRL-160, Line Item 8, Volume V, Book 6, is incorporated into this report by reference.

Section 3

RELIABILITY AND MAINTAINABILITY ANALYSES

3.1 CRITICALITY ANALYSIS

As a guide to emphasis in subsequent checkout technique studies, an analysis has been made of the overall subsystem and major component criticality (failure probability) of the Space Station subsystems and equipment. As an input to the Checkout Requirements Analysis Task, this data along with the failure mode and effects data will be useful in determining test priorities and test scheduling. Additionally, this data will aid in optimizing checkout system design to ensure that confidence of failure detection is increased in proportion to added system complexity and cost.

3.1.1 CRITICALITY ANALYSIS PROCEDURE

A criticality number (related to failure probability) was generated for each major subsystem component. This number is the product of: (1) the component failure rate (or the reciprocal of mean-time-between-failure), (2) the component's anticipated usage or duty cycle, and (3) an orbital time period of six months, or 4,380 hours. Six months was chosen as the time period of interest to allow one missed resupply on the basis of normal resupply occurring at three-month intervals. The criticality number, then, is the failure expectation for a particular component over any six-month time period.

For visibility, the major components of each subsystem analyzed have been ordered according to the magnitude of their criticality numbers. This number, however, should not be considered as an indication of the real risk involved, since it does not take into account such factors as redundant components, subsystem maintainability, and the alternate operational procedures available.

Overall subsystem criticality has been determined by a computerized optimization process whereby spares and redundancy are considered in terms of a trade-off between increased reliability and weight. This determination, therefore, reflects not only the failure probability of subsystem components, but also the probability that a spare or redundant component may not be available to restore the subsystem to operational status. The methodology used is described in Section 9, Long-Life Assurance Study Results, DRL 13 (Preliminary Subsystem Design Data), Volume III (Supporting Analyses), Book 4 (Safety/Long Life/Test Philosophy) from the MDAC Phase B Space Station Study. Component-level failure mode and criticality data are presented in subsequent paragraphs.

3.1.2 SUBSYSTEM CRITICALITY DATA

Reliability for the Structural and Mechanical Subsystem for six months is 0.995 and requires 75 pounds of seals and meteoroid patches to achieve. This equates to a subsystem criticality numeric of 5×10^{-3} for each six-month orbital interval. This value implies that there is a 0.5 percent risk that adequate spares will not be available when required or that a puncture in the pressure shell will occur that cannot be repaired. Component-level criticality numbers in Table 3-1 were estimated directly since conventional mean-time-between-failure numerics are not appropriate for structural components.

3.2 FAILURE EFFECTS ANALYSIS

Based upon the baseline subsystem descriptions, each major subsystem component was assessed to determine its most probable failure mode(s), and the "mission effect" associated with this failure mode(s). The "mission effect" is noted to provide a brief explanation of Space Station behavior if the particular failure mode should occur (e.g., experiments degraded, crew hazard, etc.). The explanation generally does not, however, consider the offsetting effects of backup redundancy or spares since there would be practically no effect if these factors were considered.

In addition, the effect of failure is categorized into the following criticality classes:

(a) Category I - Failure could cause a loss of life.

(b) Category II - Failure could cause the loss of a primary mission objective.

(c) Category III - Failure could cause the loss of a secondary mission objective.

(d) Category IV - Failure results in only a nuisance.

In most cases, Category II and Category III failures are not distinguishable because primary and secondary mission objectives have not been identified to the level of detail required to permit such separation.

Component level failure mode and criticality classification data are shown in Table 3-2.

Table 3-1. Structures Subsystem Criticality Ranking

Component	Single Unit Criticality (10^{-6})	Conditioned Loss Criticality (10^{-6})	Remarks
Primary Structure	1,000	500	Considers that 1/2 the risk can be negated by patching meteoroid penetrations, utilizing makeup O_2 for leakage, and stopping meteoroids with the meteoroid shield
Radiator	1,000	500	Considers that 1/2 the risk can be deleted by replacing segments and isolating leaks
View Port Seals	500	100	Leakage can be made up by emergency O_2
Tunnel Hatches	500	100	Redundant seals and more than one exit from compartment exist
Docking Ports	360	10	Considers repair of docking ports plus capability of docking at any port if one docking mechanism is damaged
Main Airlock	300	10	Replaceable seals and makeup O_2. EVA can also be accomplished via forward section
Antenna Deployment Mechanism	100	10	Provides for less than optimum coverage if one antenna is out and EVA to repair
Fairings	100	10	EVA can release

Table 3-2. Structure Subsystem

Major Subsystem Component	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cycle (%)	Criticality Unit (4380 hrs X B/A X 10^{-6})
Primary Structure	Meteoroid penetration Docking collision Shrapnel from pressure vessel rupture	Loss of mission objectives & crew safety but are secondary failures	I	--	---	100	1,000
Viewport Seals	Leakage	Cat. I - gross leakage would require crew evacuation of a compartment	II	7	---	100	500
Tunnel Hatches	Leakage Jammed closed Jammed open	Cat. I - crew safety hazard if one compartment were contaminated or on fire	I	5	---	100	500
Docking Ports	Leakage Docking collision	Cat. I - crew safety if extensive rupture occurs requiring immediate crew evacuation of a compartment	I	7	---	100	360

Table 3-2. Structure Subsystem (Continued)

Major Subsystem Component	Failure Mode(s)	Mission Effect	Failure Category	No. of Units	(A) MTBF/Source Thousands of Hours	(B) Duty Cycle (%)	Criticality Unit (4380 hrs X B/A X 10^{-6})
Antenna Deployment Mechanism	Servo motor shorts	Loss of optimum coverage	III	4	---	1 cy.	400
Main Airlock	Leakage Rupture	Loss of normal EVA egress & ingress route	II	1	---	100	300
Radiator	Leakage Burst	Experiment loss or curtailment	II	1	---	100	1,000
Fairings (Nose Cone) (Sensors)	Won't separate Hangup	Loss of prime experiments Loss of automatic control	II	4	---	1 cy.	100

3.3 MAINTENANCE CONCEPT ANALYSIS

Maintenance concepts defined for Space Station subsystems are intended to facilitate their preservation or restoration to an operational state with a minimum of time, skill, and resources within the planned environment. General maintenance concepts and analyses are summarized in Section 7.

3.4 LINE REPLACEABLE UNIT ANALYSIS

General guidelines and criteria for the definition of LRUs were established and these along with the maintenance philosophies reported in Section 3.3 were used to determine at what level line maintenance would be performed. For the Space Station subsystems specific justification applicable to LRU selection for the particular subsystem under examination was derived from the guidelines and these justifications are presented along with the LRU listing. The "functional LRUs" were then considered in the light of the standard electronic packaging scheme and actual LRUs were defined and listed. The method employed and the results achieved are discussed for both cases in the following sections.

The definition of Line Replaceable Units (LRUs) is keyed to repairing subsystems in an in-place configuration with the LRU being the smallest modular unit suitable for replacement. General factors considered in identifying subsystem LRUs include: (1) maintenance concepts developed and defined in Section 3.3; (2) the component-level failure rates delineated in the criticality analyses of Section 3.1; (3) the amount of crew time and skill required for fault isolation and repair; (4) resultant DMS hardware and software complexity; and (5) subsystem weight, volume, location, and interchangeability characteristics. Listings of LRUs and more specific justification for their selection follows.

Selection of LRUs for the Structures Subsystem is based primarily upon specific failure characteristics of subsystem comments. The selection has also been based upon a replacement level which can be accomplished with ordinary tools and skills, and without a requirement for precision alignment and/or special processes, environment, or facilities. The analysis has resulted in the LRU list shown in Table 3-3.

The LRUs defined fall into the following general failure categories:

- Soft parts subject to scuffing, wear, puncture, possible age degradation, or other surface marring. Examples include hatch seals, struts with "O" rings, the inflatable airlock, and view port windows.

- Items subject to physical damage from outside physical impact/collision (e.g., docking) or misuse. Examples include docking latches, the antenna boom, the complete hatch assembly, and isotope unit handling aids.

- Functional electromechanical units which, during the ten-year life of the Space Station, could experience unexpected wear or internal part failure. Examples include the despin module antirotation drive unit, the antenna boom drive unit, the cargo handling hoist assembly, and the electric drive unit used in handling the isotope.

Table 3-3. Structures

LRU	Quantity
Docking Mechanism Shock Struts	64
Docking Port Inflatable Seals	14
Hatches and Airlock Doors Inflatable Seals	18
Inflatable Airlock	1
View Port Window Assembly	25
Hatch Temperature Indicators	32
Hatch Pressure Indicators	32
Hatch Assembly	16
Despin Module Drive Unit	1
Cable Deployment Module Drive	1
Docking Port Seal Latches	32
Antenna Boom	4
Antenna Boom Drive Unit	4
Cargo Handling Hoist	2
Cargo Hoist Cable	2
Electric Drive Unit, Isotope System Handling	2
Handling Aids, Isotope System	4

Table 3-3. Environmental Control and Life Support

LRU	Quantity Required	Quantity Standby Redundant
High Pressure Gas Tank	12	
Flow Restrictor	30	
Shutoff Valve, Solenoid W Manual OR	27	
Quick Disconnect	95	
3-Way Valve, Electrically Operated	34	
Electric Heater	20	
Pressure Regulator with Relief	2	2
Pressure Control	1	1
O_2 Sensor	1	1
3-Way Valve, Pressure Actuated	1	1
Shutoff Valve, Manual	275	
Relief and Dump Valve	2	2
Low Pressure Tank	9	
Pressure Regulator	5	
Compressor	9	
Heat Exchanger, Liquid to Gas	2	
Check Valve	40	
Air Bypass Valve	2	
Fan	20	
Pump	33	7
Condensing Heat Exchanger	8	
Temperature Controller	7	
Temperature Sensor	8	
Adsorption Cannister	19	
CO_2 Sensor	8	

Section 4

CHECKOUT STRATEGIES

4.1 SUBSYSTEM CHECKOUT STRATEGY

Prior to any further requirements analysis, it is necessary to develop a checkout strategy for all Space Station subsystems to meet the checkout objectives of the Space Station OCS. The objectives of the Space Station OCS can be summarized as follows:

- To increase crew and equipment safety by providing an immediate indication of out-of-tolerance conditions
- To improve system availability and long-life subsystems assurancy by expediting maintenance tasks and increasing the probability that systems will function when needed
- To provide flexibility to accommodate changes and growth in both hardware and software
- To minimize development and operational risks

Specific mission or vehicle-related objectives which can be imposed upon subsystem level equipment and subsystem responsibilities include the following:

- OCS should be largely autonomous of ground control.
- Crew participation in routine checkout functions should be minimized.
- The design should be modular in both hardware and software to accommodate growth and changes .
- OCS should be integrated with, or have design commonality with, other onboard hardware or software .
- The OCS should use a standard hardware interface with equipment under test to facilitate the transfer of data and to make the system responsive to changes.
- Failures should be isolated to an LRU such that the faulty unit can be quickly removed and replaced with an operational unit.

- A caution and warning system should be provided to facilitate crew warning and automatic "safing" where required.

- Provisions must be included to select and transmit any part or all of the OCS test data points to the ground.

To attain these objectives via the use of an Onboard Checkout System which is integrated with the Data Management System, checkout strategies have been developed which are tailored to each Space Station subsystem.

Special emphasis has been applied to a strategy for checkout of redundant elements peculiar to each subsystem. The degree to which each of these functions is integrated into the DMS is also addressed.

4.1.1 SPACE STATION SUBSYSTEMS

Each major Space Station subsystem was examined with respect to the required checkout functions. The checkout functions associated with each subsystem are identified and analyzed as to their impact on the onboard checkout task. The functions considered are those necessary to verify operational status, detect and isolate faults, and to verify proper operation following fault correction. Specific functional requirements considered include stimulus generation, sensing, signal conditioning, limit checking, trend analysis, and fault isolation.

The Structures Subsystem consists of the basic Space Station structure (shell, bulkheads, etc.) and the associated equipment such as meteoroid shields, hatches, air locks, docking systems, antenna booms, and artificial gravity systems.

4.1.1.1 Checkout Functions

Checkout functions associated with the Structures Subsystem are relatively few and simple. These are primarily related to the verification of compartment integrity, hatch and docking port status, and to the deployment of the high gain antennas and artificial gravity systems. The checkout task is characterized by low measurement data rates, absence of special test stimulus requirements, and by comparatively uncomplicated computation requirements.

- Stimulus Generation - No stimuli, other than normal operational control signals, are required for checkout of the Structures Subsystem. Operational control requirements, as tabulated in Appendix I, consist of discrete commands for seal pressurization and similar functions.

- Sensing - Sensing requirements of the Structures Subsystem are almost entirely limited to measurement of mechanical parameters, such as door, latch and actuator position and to the measurement of gas pressure in compartments, seals, and associated tankage. These requirements are listed in Appendix I.

- Signal Conditioning - A minimum of special signal conditioning is required since many of the measurements, particularly the position measurements, are implemented in a manner (i. e., with limit switches) which is directly compatible with the Data Acquisition System. Conditioning may be required for the pressure transducers, depending upon the type selected, and for the rotational sensor. Such conditioning, where required, performs conversion and scaling of the sensor outputs and provides a standard 0-5 Vdc output to the Data Management System.

- Limit Checking - Periodic or continuous limit checking is required for selected pressure parameters, including seal pressures, compartment and airlock pressures, and docking ring compression strut pressures.

- Trend Analysis - Analysis of the Structures Subsystem has revealed no potential application of long term trend analysis techniques. Short term analysis of compartment and seal pressures is required, however, to verify pressure integrity and to detect and isolate meteoroid punctures and other leaks.

4.1.1.2 Redundant Element Checkout

Redundancy in the Structures Subsystem takes the form of installed and independently active elements. A typical example is the dual seals on all pressure hatches. These redundant elements, being fully operational rather than of a standby nature and being independently instrumented and controlled, require no special treatment from the checkout standpoint.

4.1.1.3 Integration with Data Management Subsystem

The checkout interface between the Structures Subsystem and the DMS consists of the measurement parameters listed in Appendix I of the Task 1 Final Report. All measurements at the interface are in the form of normalized 0-5 Vdc signals and are directly compatible with the Remote Data Acquisition Units. Test sequencing and control are provided by the DMS, as is operational control.

4.2 INTEGRATED CHECKOUT STRATEGY

This analysis identifies the integrated checkout functions associated with Space Station subsystems during the manned orbital phase of the mission. These functions are depicted in Figure 4-1 and are those required to ensure overall availability of the Space Station. Characteristic of integrated testing is the fact that the test involves subsystem interfaces, and, therefore, test objectives are associated with more than one subsystem.

4.2.1 INTEGRATED CHECKOUT STRATEGY

Six checkout functions have been identified:

- Caution and warning
- Fault detection
- Trend analysis
- Operational status
- Periodic checkout
- Fault isolation

These functions represent a checkout strategy of continuous monitoring and periodic testing with eventual fault isolation to a line replaceable unit (LRU). Under this aspect the functions are grouped as -

CONTINUOUS MONITORING	PERIODIC TESTING	FAULT ISOLATION
• Caution and warning	• Automatic tests	• Localize to SS
• Fault detection	• Operational Verification	• Isolate to RLU
• Trend analysis		
• Operational status		

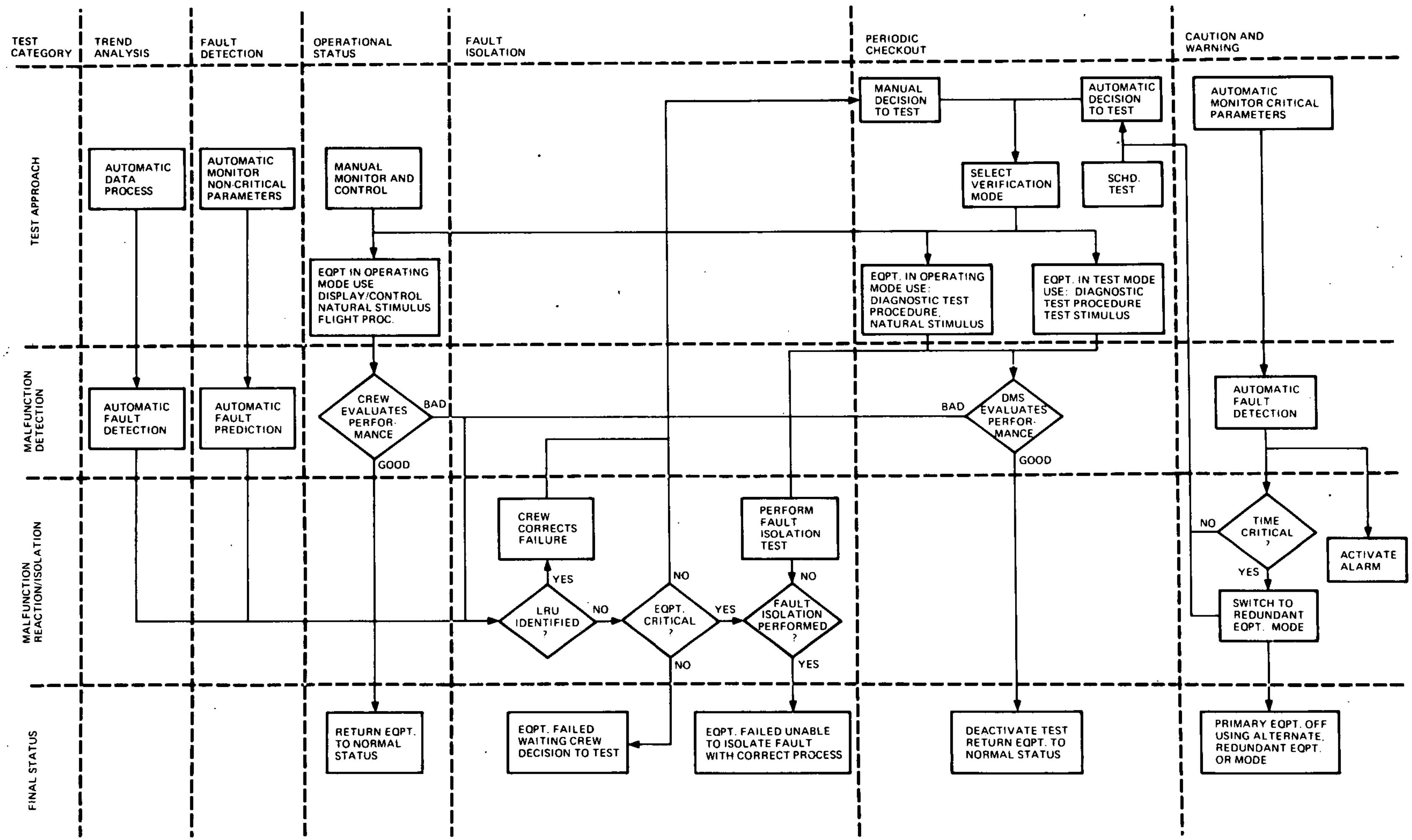


Figure 4-1. Integrated Checkout Functional Flow

General characteristics of these groups are defined below:

4.2.1.1 Continuous Monitoring

Continuous monitoring is not a test per se. It is a concept of continuously sampling and evaluating key subsystem parameters for in/out-of-tolerance conditions. This evaluation does not necessarily confirm that the subsystems have failed or are operating properly. The evaluation is only indicative of the general status of the subsystems. For example, a condition exists where the integrated subsystems are indicating in-limit conditions, but during the next series of attitude control commands, an error in Space Station position is sensed and displayed. The malfunction indication is only indicative of an out-of-tolerance condition of an integrated function. Final resolution of the problem to a subsystem and eventually to LRU will require diagnostic test procedures that are separate from the continuous monitoring function.

There are situations in which the parameters being monitored are intended to be directly indicative of the condition of a subsystem or an LRU. Examples of these include tank pressures, bearing temperatures, and power source voltages. However, even in these simpler cases when a malfunction is detected, an integrated evaluation will be performed to ascertain that external control functions, transducers, signal conditioning, and the DMS functions of data acquisition, transmission, and computation are performing properly. This evaluation will result in either a substantiation of the malfunction or identification of a problem external to the parameter being monitored.

Figure 4-1 shows the logic associated with each function in the continuous monitoring group, as well as the integrated relationships between these and the total checkout functions. The caution/warning and fault detection functions are alike in their automatic test and malfunction detection approaches, but are different in terms of parameter criticality and malfunction reaction. The caution/warning function monitors parameters that are indicative of conditions critical to crew or equipment safety. Parameters not meeting this criticality criteria are handled as fault detection functions. Figure 4-1 shows that in the event of a critical malfunction, automatic action is initiated to warn the crew and sequence the subsystems to a safe condition. Before this automatic action is taken, the subsystems must be evaluated to ascertain that the failure indication is not a false alarm and that the corrective action can be implemented. After the action is taken, the subsystems must be evaluated to determine that proper crew safety conditions exist. Since automatic failure detection and switching can be integral to subsystem design (self-contained correction) and subsystems can be controlled by the operational software or manual controls, it is imperative that the status of these events be maintained and that the fault detection and correction software be interfaced with the prime controlling software. For malfunctions that are not critical, the crew is notified of their occurrence, but any subsequent action is initiated manually.

The next continuous monitoring function, trend analysis, automatically acquires data and analyzes the historical pattern to determine signal drift and the need for unscheduled calibration. It also predicts faults and indicates the need for diagnostic and fault isolation activities. An example of a parameter in this category is the partial pressure of nitrogen. Nitrogen is used to establish the proper total pressure of the Space Station. Since it is an inert gas, the only make-up requirements are those demanded by leakage or airlock operation. The actual nitrogen flow rate is measured, and calculations are performed which make allowances for normal leakage and operational use. When these calculations indicate a trend toward more than anticipated use, the crew is automatically notified and testing is initiated to isolate the problem to the gas storage and control equipment or to an excessive leak path. The historical data is not only useful in predicting conditions but is also useful in providing trouble-shooting clues. The data might reveal, for example, that the makeup rate increased significantly after the use of an airlock. This could lead directly to verifying excessive seal leakage.

The final continuous monitor function is in operational status. This function is performed by the crew and is nonautomatic with the exception of the DMS computer programs associated with normal Space Station operational control and display functions. The concept of continuous monitoring recognized and takes advantage of the crew's presence and judgment in evaluating Space Station performance. In many instances the crew can discern between acceptable and unacceptable performance, and they can clearly recognize physically-damaged equipment or abnormal conditions.

4.2.1.2 Periodic Testing

As opposed to continuous monitoring, periodic testing is a detailed evaluation of how well the Space Station subsystems are performing. Figure 4-1 shows that periodic testing is not accomplished by any one technique. Rather, a combination of operational and automatic test approaches is employed. The actual operational use of equipment is often the best check of the performance of that equipment. Operation of Space Station equipment and use of the normal operating controls and displays will be used in detecting faults and degradation in the subsystems. This mode of testing is primarily limited to that equipment whose performance characteristics are easily discernible, such as for motors, lighting circuits, and alarm functions.

Automatic testing is performed in two basic modes:

- With the subsystems in an operating mode, the DMS executes a diagnostic test procedure which verifies that integrated Space Station functions are being properly performed under normal interface conditions in response to natural or designed stimulation. This mode of testing allows the evaluation of Space Station performance without interrupting mission operations.

- For those situations where the integrated performance or interface compatibility between subsystems cannot be determined without known references or control conditions, the DMS will execute a diagnostic procedure in a test mode. In this mode, control, reference, or bias signals will be switched in or superimposed on the subsystems to allow an exact determination of their performance or localization of problem between the interfaces. Since the test mode may temporarily inhibit normal operations, the DMS must interleave the test and operational software to maintain the Space Station in a known and safe configuration.

The scheduled automatic tests are performed to verify availability or proper configuration of "on-line" subsystems, redundant equipment, and alternate modes.

- Periodic Verification of "On-Line" Subsystems - The first checkout requirement is a periodic verification that on-line subsystems are operating within acceptable performance margins. The acceptable criteria for this evaluation is based on subsystem parameter limits and characteristics exhibited during Space Station factory acceptance or pre-flight testing. The rejection criteria and subsequent decision to repair or reconfigure subsystems is based on the criticality of the failure mode. If the subsystems appear to be operating properly, but the test clearly indicates an out-of-tolerance condition, then one of the following alternatives must be implemented:

  - If the failure mode is critical, the crew normally takes immediate action to isolate and clear the problem.

  - If the failure mode is not critical, the crew can take immediate action, schedule the work at a later time, or wait until the condition degrades to an unacceptable level.

- Redundant Equipment Verification - A second checkout requirement is verifying that standby, off-line, or redundant equipment and associated control and switching mechanisms are operable. The acceptable/rejection criteria for these evaluations is identical to those for normally operating equipment. A primary distinction of this function is that equipment may have known failures from previous usage or tests. This situation occurs when the crew has knowledge of a failure but has not elected to perform the necessary corrective action. The checkout function then becomes one of equipment status accounting and maintenance/repair scheduling. The status information is interlocked with mission procedures and software to preclude activation of failed units while they are being repaired or until proper operation following repair is verified.

- Alternate Mode Verification - The third checkout function is verifying the availability of alternate modes of operation. This function is essentially a confidence check of the compatibility of subsystems'interaction and performance during and after a change in the operating mode. To some extent this function overlaps with redundant equipment verification, but is broader in scope in that it verifies other system-operating characteristics. For example, some modes will involve manual override or control of automatic functions or automatic power-down sequences.

4.2.1.3 Fault Isolation

Fault isolation to an LRU is a Space Station goal. As shown in Figure 4-1, fault isolation testing is initiated when malfunction indications cannot be directly related to a failed LRU. The integrated test functions associated with fault isolation are localizing a malfunction to a subsystem or to an explicit interface between two subsystems and identifying the subroutine test necessary for LRU isolation. In structuring this relationship between integrated subsystem tests for fault localization and subroutine tests for fault isolation, the DMS, in conjunction with the test procedure documentation, must establish an effective man-machine interface so that in the event of an unsolved malfunction the crew will be able to help evaluate the condition and determine other test sequences necessary to isolate the problem. To accomplish this requirement, the DMS must be capable of displaying test parameters and instructions in engineering units and language and be capable of referencing these outputs to applicable documentation or programs that correlate test results to corrective action required by the crew.

Section 5

ONBOARD CHECKOUT TEST DEFINITIONS

5.1 SUBSYSTEM TEST DEFINITIONS

The on-orbit tests required to insure the availability of the Space Station subsystems are defined herein. Also delineated are the measurement and stimulus parameters required to perform these tests. Two discrete levels of testing are defined, i.e., continuous status monitoring tests for fault detection of critical and noncritical parameters, and subsystem fault isolation tests for localization of faults to a specific Line Replaceable Unit. In addition to these two levels, tests are defined for periodic checkout and calibration of certain units, and parameters requiring analysis of trends are defined.

Due to the software module approach to DMS checkout, it was deemed necessary to estimate the CPU time and memory required to implement these modules along with an assessment of the services required from an Executive Software System to control the checkout.

These test descriptions, measurement, and stimulus information provided for each subsystem, and the software sizing information provided for the Data Management System provide the data required to estimate the checkout impact on the DMS software and hardware. Table 5-1 is a summary of the measurement and stimulus requirements for the Space Station.

The Structural Subsystem forms and maintains the compartment divisions of the Space Station. It provides a pressure shell/structural shield designed for high damage resistance from external projectiles (meteorites), and eliminates stresses due to orbital thermal cycling.

Ports are provided on the exterior structure shell to accommodate docking of resupply/logistic and experiment modules which enhance orbital life and versatility of the basic station design.

The Structures Subsystem also includes provisions needed for deployment of the spent S-II stage as a counterweight for the artificial gravity mode of operation.

Operational assessment of the Structures Subsystem elements is generally accomplished by monitoring of measured system parameters, and to a significant extent, by visual inspection. Operational measurements for the subsystem are predominantly of the event monitoring type intended to inform the crew of the

Table 5-1. Measurement/Stimulus Summary

SUBSYSTEM	STIMULUS					RESPONSE			STATUS MONITORING								
	Analog	Bilevel	Digital	Pulse	RF	Analog	Bilevel	Digital	Total	Non-Critical	Caution	Warning	Periodic Checkout	Cali-bration	Trend	Fault Isola-tion	Remarks
Guidance, Navigation and Control	20	146	62	6		127	161	70	592	130	16		516	74	74	592	
Propulsion - Low Thrust		134				120	124		378	152	14		378	48	8	378	
Propulsion - High Thrust		126/62				287/117	123/63		536/242	80/28	33/15	14/10	536/242	259/111	117/43	482/222	Art-g/Zero-g periods
Environmental Control/ Life Support	34	111				691	280		1116	139	205	32	1116		135	1116	172 Caution/Warning Signals are for IVA/EVA
RF Communications	37	206	36		77	131	286	28	801	58			576	24	93	801	
Structures	15/16	21/19				60/53	75/66		174/154	7			123/104			174/154	
Electrical Power - TCD	52	1952				292	1292	20(1)	7608	1404	20		724		134	3608	(1) Twelve of these take pulse form
Electrical Power - Solar Array/Battery		1916				4044	928		6780	3704	12		2184		332	6788	
Data Management			53			33	188	83	357	357			62	62	62	357	
Total	151/169	4512/ 4446	151	6	77	5785/ 5628	3457/ 3388	201	14,350/ 14,035	6031/ 5979	300/282	46/42	5110/ 5902	467/ 319	935/ 861	14,266/ 14,016	

immediate configuration/status of the subsystem. Functions to be monitored and displayed included position/event data on docking rings, hatches and airlock doors, and antenna booms. Analog measurements/display include counterweight position and pressures, temperatures, and power monitoring of compartment divisions and functional units which provide pre and post event data to the crew for condition assessment. It should be noted that the operational data requirements for this subsystem are extremely event-oriented and that the frequency of use is low (ave 1/mo). Hence, the impact upon the Data Management Subsystem for real-time continuous data display and computation is also minimal (e.g. data callup in lieu of full-time dedication is acceptable). Measurement and stimuli requirements for the Structures Subsystem are contained in Appendix I-6 of the Task 1 Final Report.

5.1.1 STATUS MONITORING

Due to the nature of the Structures Subsystem the requirements for continuous status monitoring for purposes of fault detection are quite limited. Such monitoring requirements that do exist utilize selected operational status parameters such as temperature and pressures. Required sampling rates are relatively low and are not critical. Acceptance rejection criteria are based upon comparison of measured values with predetermined limits. Support from the EC/LS Subsystem monitor of atmosphere consumption is utilized for detection of abnormal compartment leakage. Detection of out-of-limit conditions results in notification of the crew. Since no safety critical functions are involved, no automatic corrective action is required. Fault isolation is accomplished by combined crew/automatic procedures. Automatic fault detection is heavily supplemented by crew observation of normal subsystem status displays and of the actual equipment during operation.

No caution/warning functions have been identified in association with the Structures Subsystem. Certain related functions such as hull leaks are covered by EC/LS caution/warning functions.

5.1.2 TREND ANALYSIS

No trend analysis requirements have been identified for this subsystem.

5.1.3 PERIODIC CHECKOUT AND CALIBRATION

Periodic checkout of the Structures Subsystem elements is planned to occur either prior to a scheduled event such as module docking and artifical-g deployment/termination or during specific operational times such as shift changes where status information pertaining to compartment configuration (hatch positions) and antenna positions is of interest to the oncoming crew.

Functional checkout of the docking mechanism, which includes visual inspection and extension/retraction of the docking ring is conducted prior to a scheduled docking event to verify operation of the mechanism before committing the arriving module to that port location. This checkout is scheduled sufficiently in advance to permit reassignment of the module in the event of malfunction. Likewise, periodic start-of-shift checks of the station configuration are planned to alert the oncoming crew as to overall subsystem status.

Periodic review of EC/LS atmosphere consumption trend analysis is also planned to assess leakage of the pressurized compartment(s) to establish "as is" acceptance or need for corrective action.

5.1.4 FAULT ISOLATION

The fault isolation process to the LRU level for the Structures Subsystem lacks the complexity generally associated with electronic subsystems due to the nature of the hardware elements involved. In most instances malfunctions are obvious from the operational data being displayed or by visual inspection, and therefore require a minimum of DMS support. Isolation of leaks in the pressure shell of the station will utilize a combination of pressure decay, visual inspection, and sonic detector techniques. Pressure decay tests, accompanied by acoustical leak sensors on the shell surface, will permit isolation to a specific compartment/location. If the leakage occurs in association with an event such as EVA or docking visual inspection for seal/structural damage of the hatch/door involved will be utilized. Scuffing, wear, or puncture of a seal will be suspect. Isolation of leaks in the basic structure shell will utilize the ultrasonic detection technique which employs the use of portable detectors capable of sensing ultrasonic energy in the frequency range of 35-50 KHz produced by gas flow through an orifice.

5.2 INTEGRATED TEST DEFINITION

The task of ensuring overall Space Station availability is primarily dependent upon the proper structuring of individual subsystem tests. The ability to test the subsystems independent of other subsystems is directly related to the number and types of interfaces. As shown in Figure 5-1, the DMS and Electrical Power Subsystems (EPS) interface with every other Space Station subsystem. In addition, the EC/LS Subsystem provides cooling to most of the electronic packages.

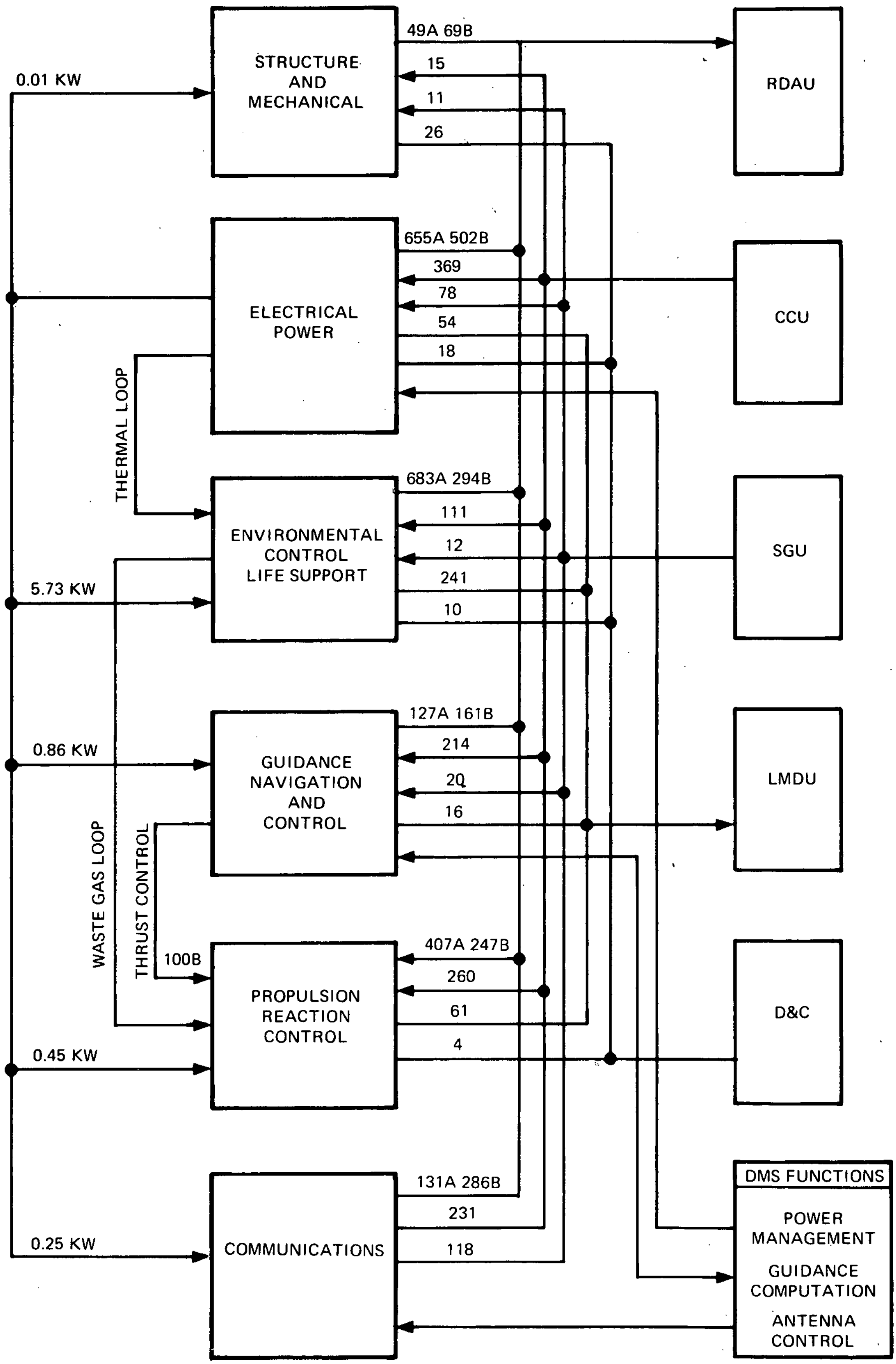


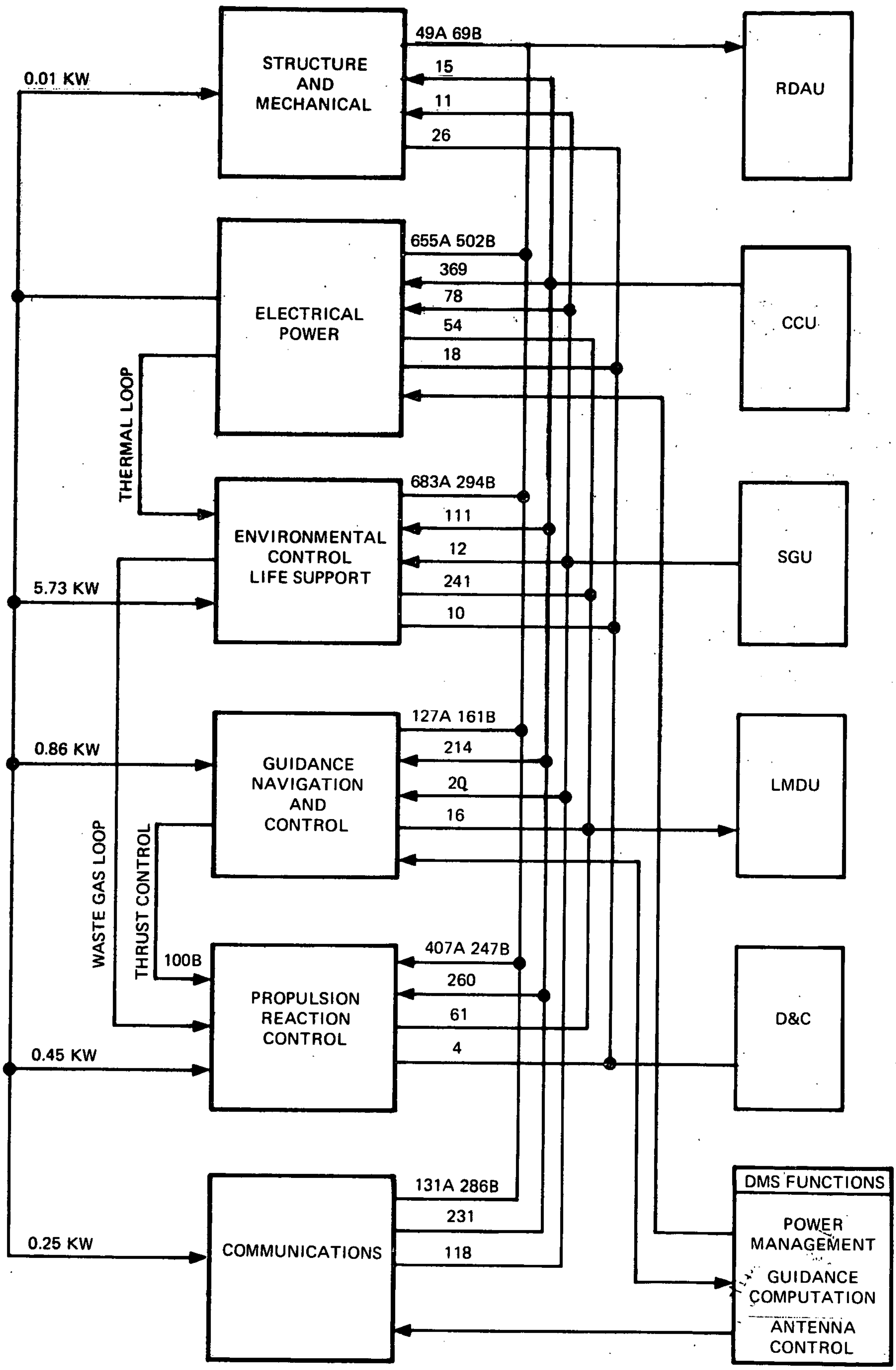
Figure 5-1. Subsystem Interfaces

This situation demands that in constructing the test for a subsystem these interfaces be taken into account so that erroneous or ambiguous test results will not be obtained. In other words, before detailed subsystem fault isolation tests are initiated, a higher level of testing should be performed to verify that all interfaces and Space Station conditions that influence the subsystem are proper. Properly designed, these higher-level tests will (1) indicate what Space Station conditions must be verified, maintained, or changed; (2) localize the malfunction to a single subsystem; and (3) identify the subroutine test necessary for fault isolation.

Since the DMS interfaces with all of the Space Station subsystems and is used as the OCS, it would appear that all of the tests would be integrated. However, this is not a proper interpretation. When the DMS is used to verify the performance of another subsystem, it must first establish itself as a test standard against which the subsystem parameters are compared. Subsequent to this verification, the test is dedicated to the evaluation of the subsystem. This test would be considered as an independent test since the objective of the test was to verify the subsystem and not the DMS. For a test to be considered as an integrated test it must meet one or more of the following conditions:

- Test objectives associated with more than one subsystem
- Test involves subsystem interfaces
- Test requires proper operation of other subsystems

In several cases, the DMS must simultaneously perform the dual role of OCS and functional elements. As an example, the DMS has a functional interface with the GN&C and Prop Subsystems for the computation of guidance equations and the execution of commands to the control actuators. When this functional closed loop is being tested, the DMS must, in addition to performing its normal functions, execute the test routine. For this type of integrated test there must be an intrinsic relationship between the operational and test software. This relationship must be carefully considered in structuring the integrated tests since unstable or intermittent performance may be detected only in the exact operating mode under closed-loop conditions. The number of integrated tests is not extensive due to the approach of minimizing the different types of interfaces between Space Station subsystems. For example, interfaces between the DMS and other subsystems are largely standardized. As a result, relatively common tests can be designed for verification of the multitude of DMS subsystem interfaces or for localization of a fault to one side of a DMS subsystem interface.



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5.2.1 EC/LS - EPS ISOTOPE/BRAYTON INTERFACE

The Environmental Control/Life Support (EC/LS) Subsystem interfaces with the EPS Isotope/Brayton System for removal of waste heat via a fluid heat exchanger installed in the Brayton Power Conversion System. It is planned that flow rate, temperature, and pressure parameters be continuously monitored on both sides of the interface as part of normal EPS and EC/LS Subsystem checks.

5.2.2 EC/LS - LOW-THRUST PROPULSION INTERFACES

The EC/LS Subsystem interfaces the low-thrust portion of the Propulsion Subsystem to supply unreacted CO_2 from the CO_2 removal assembly, methane by-products from the CO_2 conversion assembly, and excess water. The Propulsion Subsystem uses these biowaste fluids in the Low-Thrust System as propellant. The interface is controlled by the DMS or by manual control to satisfy such parameters as propellant and pressurant selection. These parameters are primarily a function of impulse requirements and available stores. Checkout of the interface is required to verify proper valve and pump operation for the transfer of the waste gases and excess water.

Section 6

SOFTWARE

6.1 GENERAL CONSIDERATIONS

The recommended software checkout startegy involves a sequence of detecting faults, isolating faults to a failing LRU or LRUs, and reconfiguring the system to continue operation while the failures are being repaired.

This recommendation was developed by evaluating each subsystem with respect to the three general requirements of fault detection, fault isolation, and reconfiguration.

Fault detection incorporates both the recognition of failure occurrence, and the prediction of when a failure can be expected to occur. The Remote Data Acquisition Units (RDAUs) continually check selected test point measurements against upper and lower limits, and notify the executive on an exception basis when a limit is exceeded. This approach avoids occupying the central multi-processor with the low-information task of verifying that measurements are within limits.

Trend analysis is a fault detection technique recommended for predicting the time frame during which a failure can be anticipated. Data is acquired on a basis of time or utilization, and compared with previous history to determine if a "trend" toward degraded performance or impending failure can be detected.

Another checkout requirement evaluated for each subsystem is periodic testing. This type of test is provided to exercise specific components at extended time intervals or prior to specific events, to assure operational integrity. In the event that a failure is detected, the periodic test will isolate to the failing Line Replaceable Unit (LRU) and accomplish recertification after a repair operation.

Calibration of specific subsystem components will be required periodically, or subsequent to a repair and/or replace operation. The techniques involved are unique to the individual component; and, in some cases, require the acquisition of operational data.

Fault isolation is required when a fault is detected. When a particular fault provides an indication that a life critical failure has occurred, the fault isolation routines are automatically initiated. If the failure does not represent an immediate danger to the vehicle occupants, the crew is notified and they will initiate the fault isolation modules at their convenience.

The basic requirements of the fault isolation function is to analyze the available information relevant to a problem, and identify the LRU which is responsible for the anomaly.

Three basic approaches to meeting this requirement were considered. These are:

- Analyze each fault as an independent problem
- Analyze each fault with a state matrix which defines the possible error states of the subsystem
- Associate each fault with a specific subsystem, and evaluate that subsystem in detail

The third approach was selected on a basis of software commonality and cost effectiveness. The complexity associated with the testing can be reduced by localization of the logic associated with the analysis of the subsystem in a unique package. The software commonality will result in reduced software development and maintenance costs, while increasing the reliability of the software.

The fault isolation software is structured modularly for compatibility with the hardware structure of the subsystem. Checkout modules evaluate the performance of a specific portion of the subsystem. A convenient division for this modular structure is at the assembly level or functional area. A program module which can determine and control the sequence in which these checkout modules are executed is also required for each subsystem.

Subsequent to fault detection, the software associated with the subsystem which is most likely to contain the error will be activated.

The subsystem software will analyze the error indication, and initiate a sequence of checkout modules to isolate the problem. If successful, the crew is notified regarding the Line Replaceable Unit (LRU) to be replaced. If an error cannot be identified, the crew is informed of the situation and has an option to execute the periodic test of the subsystem.

After a fault has been isolated, reconfiguration software restores the functional capability of the subsystem. This is most commonly accomplished by exchanging a redundant element for the failing unit, or by defining an alternate path to accomplish the required function.

The Task 2 Final Report of the basic onboard checkout techniques study provides descriptions of the software requirements, definitions and design in addition to detailed flow charts of specific checkout routines.

6.2 SPACE STATION SUBSYSTEM

The basic Space Station structure provides the necessary pressurized habitat, equipment support, meteoroid protection, radiators, insulation, and docking interfaces to meet operational requirements.

The fault detection function required for the Structures Subsystem is accomplished by tables which are monitored by the OCS executive program. The tables contain the parameters which must be monitored to assure subsystem performance. These tables are transferred to the Remote Data Acquisition Unit (RDAU) via the master executive program, and limit checking is accomplished. Figure 6-1 provides a graphic description of this function.

The program described by this document is required for periodic checkout and fault isolation.

Initiation of the periodic checkout function is accomplished as the result of a keyboard entry by a crew member. It is anticipated that periodic checkout will be accomplished prior to a scheduled event such as docking, artificial "G" deployment, or during specific operational times such as shift changes where status information pertaining to hatch and docking port positions are of interest to the on-coming crew.

The fault isolation utilizes the same software modules as the periodic checkout; however, it is anticipated that analysis of the detected error will permit selection of the appropriate module to begin the required fault isolation.

This program meets the periodic testing and fault isolation requirements for the Structure Subsystem.

Four specific functional areas of the subsystem require automated checkout. They are:

- Docking Mechanisms
- Antenna Deployment Mechanisms
- Basic Structure
  - Spacecraft Access
  - Hatches
  - Hangar
  - B/I Power System Handling
- Artificial "G" Considerations

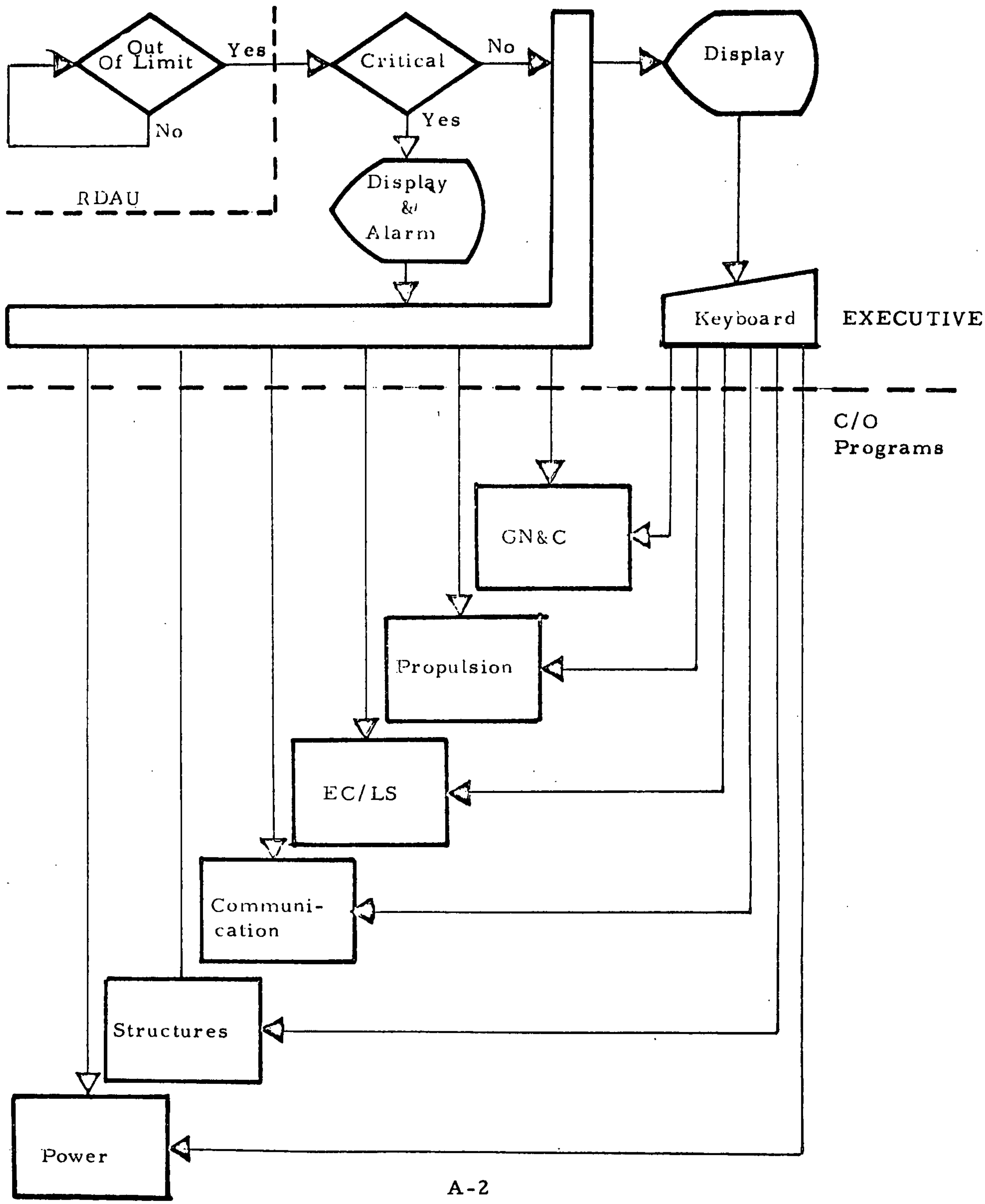

Figure 6-1. Fault Detection Logic

Figure 6-2 provides a block diagram of the functional areas of this subsystem.

The varied requirements of program execution are met by providing the opertor with the capability to select specific options of the program.

The operation of the options of this program is depicted in Table 6-2. These options include the capability to provide the current operational status, docking mechanism checkout, antenna operations checkout, and to check out the provision included for an artificial "G" environment.

6.2.1 SYSTEM REQUIREMENTS

This section describes system constraints and requirements which have influenced design.

6.2.1.1 Subsystem Definition

This program specification is based upon the subsystem definition which is available as a result of this study contract. The test points for this subsystem are currently defined at the assembly level; and consequently every failure which is detected cannot be identified with a special LRU (Refer to Table 6-1).

6.2.1.2 Docking Mechanism Checkout Module

There is no test point available to extend or retract the docking ring. The existence of a test point labeled "Docking Ring Pressure Control" has been assumed. This stimuli will permit extension and retraction of the docking ring.

6.2.1.3 Artificial "G" Checkout Module

The periodic and fault isolation test requirements indicated in the measurement and stimulus list include test points labeled "Cable Deployment Drum Travel." The information supplied by these test points can only be evaluated during an actual deployment. Consequently, these test points have been omitted for periodic and fault isolation testing. It is anticipated that additional test points will be identified in the future to assure the continuity of these measurements.

There are controls provided in the system for the Operation of the S-II latches. These latches are used to hold the S-II stage and are released during the deployment sequence. Because of the problems that could occur if the latches failed to relock during a test, these components are not exercised as a function of the periodic or fault isolation test.

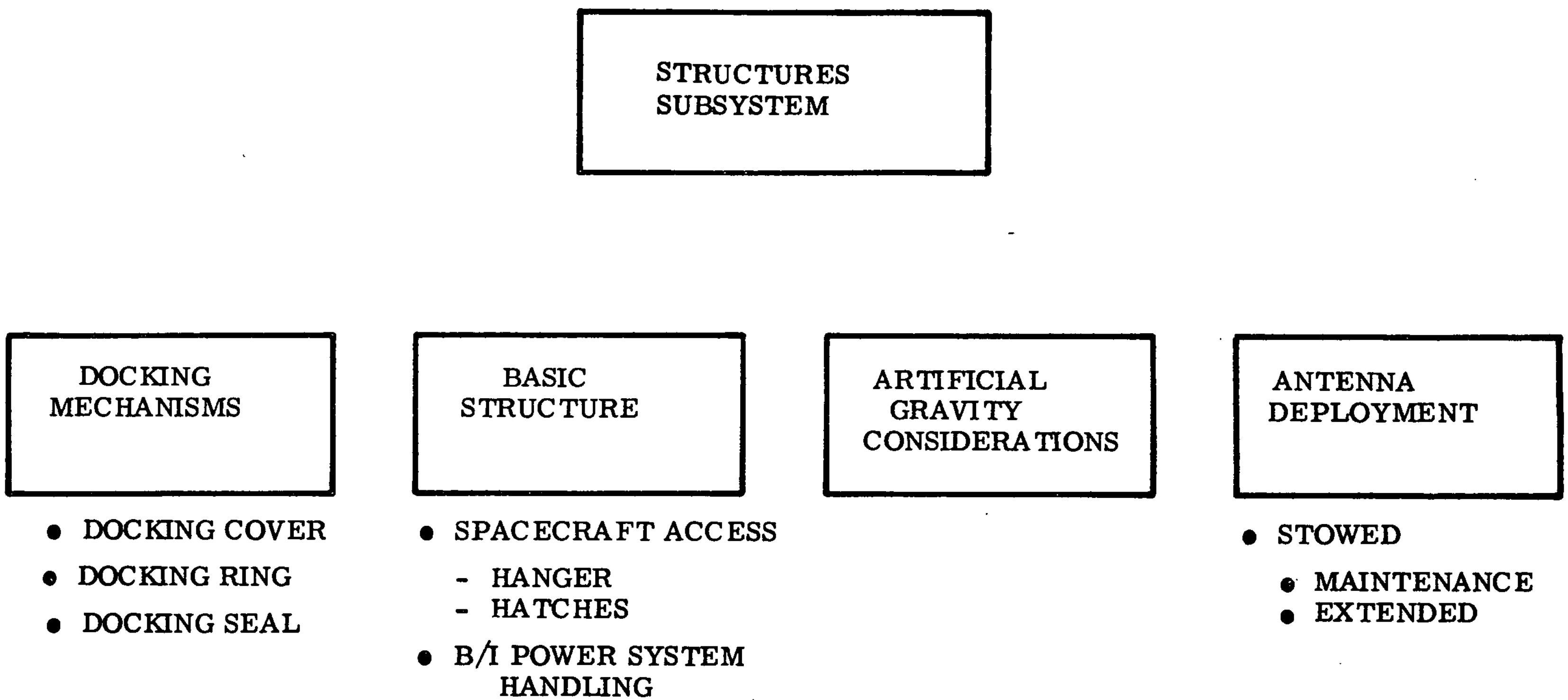

Figure 6-2. Structure Subsystem Functional Areas

Table 6-1. LRU Identification

This table includes a list of LRU types which make up the structures subsystem. Those which can be associated with specific test points are indicated by asterisks.

Table 3-1. LRU Identification

Line Replaceable Unit	Identifiable
Docking Mechanism Shock Struts	*
Docking Port Inflatable Seals	*
Hatches and Airlock Doors Inflatable Seals	
Inflatable Airlock	
Viewport Window Assembly	
Hatch Temperature Indicators	
Hatch Pressure Indicators	
Hatch Assembly	*
Despin Module Drive Unit	*
Cable Deployment Module Drive	*
Docking Port Seal Latches	
Antenna Boom	
Antenna Boom Drive Unit	*
Cargo Handling Hoist	
Cargo Hoist Cable	
Electric Drive Unit, Isotope System Handling	*
Handling Aids, Isotope System	

The checkout of the design module requires limit checking on the basis of operational information to be acquired from the operational system. Lack of definition regarding specific data and algorithms prevents consideration of this requirement in the software analysis.

6.2.1.4 Allocable Equipment

The checkout which this program must accomplish requires that the following components be indepently identifiable, and dedicated to this program for a specific time interval.

Docking Ports
Hangar
Hatches
Antennas
De-spin Module
Cable Deployment Module

6.2.2 OPERATIONAL REQUIREMENTS

This program specification defines specific operational requirements for periodic testing and fault isolation of the following areas:

- Docking Mechanism
- Hatches, Airlocks, and Viewports
- Artificial Gravity Experiment Provisions
- Antenna Deployment
- Isotope Power System Handling and Replacement Equipment

The specific program modules which meet these requirements are:

- Option selection
- Operational status
- Docking mechanism checkout
- Spacecraft access module
- Antenna fault isolation
- Isotope/Brayton power handling
- Artificial "G" checkout

A module block diagram of the program is provided in Figure 6-3.

6.2.2.1 Option Selection

This function processes the selection of options to permit the selective checkout of specific functional areas. The options selected will be determined from the parameter data supplied to the program. These options are defined in Table 6-2. The outputs of the option selection are used by the program to select the proper options for execution. Tutorial displays are also required.

The information processing program module processes the input parameter information, and executes the program module specified by the options defined in Table 6-2.

The parameter information passed to the program will be examined. If none was included, the program will execute the programmed default option of checking the operational status of specific test points. (Refer to paragraph 6.2.2.2.)

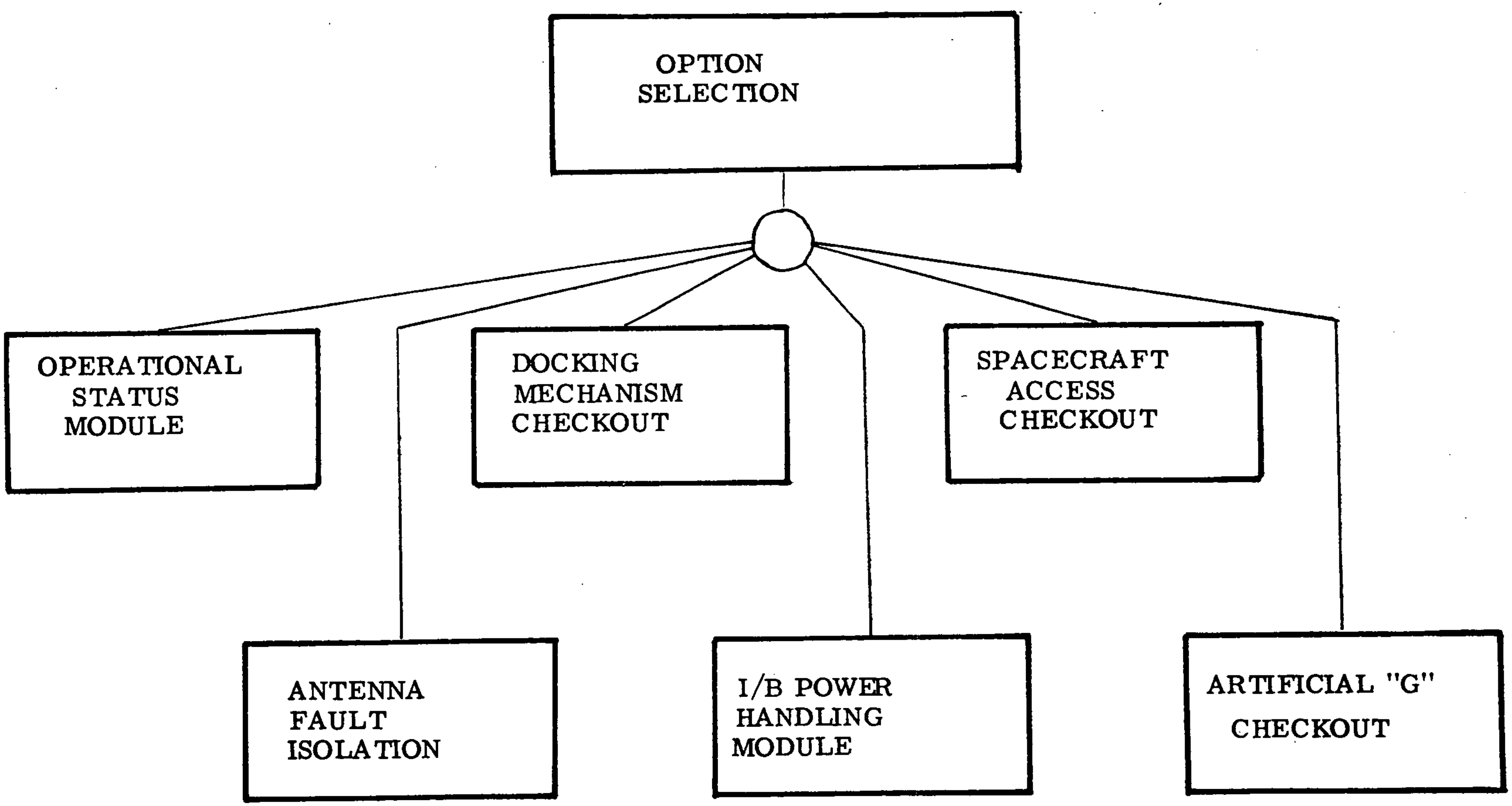

Figure 6-3. Structures Subsystem Checkout Program Modular Block Diagram

Table 6-2. Initial Program Options

Keyword	-	Program Response
STATUS	-	Execute the Operational test point status module
DOCK	-	Execute the Docking mechanism checkout module
ANTENNA	-	Execute the Antenna Fault Isolation module
SPAC	-	Execute the Spacecraft access checkout module
OPTN	-	Display Options
IBP	-	Execute the Isotope/Brayton Power handling module
ATRG	-	Execute Artificial G checkout module
FI	-	Execute fault isolation routines in addition to periodic check.

If the keyword OPTN is included in the parameter data, the program displays the available options and waits for the operator to enter his selection.

Any combination of keywords may be entered; however, they must be separated by a comma. The introduction of a blank character will be used to terminate the input string.

As the keywords are identified, an associated flag is set to indicate the function to be accomplished. The program will then examine each flag and transfer control to the appropriate module for execution.

6.2.2.2 Operational Status

This module is executed to provide the crew with information relating to the current status of the docking ports, hatches, and hangar door positions.

The inputs for this function are obtained from the data base table which the executive monitors to keep track of the status of various system components. This information is based on data received from the following test points:

- Docking Ring Position - This test point indicates if the docking ring is extended or retracted.
- Docking Port Cover Position - This test point indicates if the docking port cover is open or closed.
- Hatch Position Open/Close - Two measurements are required for each hatch to determine if it is opened or closed. One test point indicates the hatch is open, the other indicates the hatch is closed.
- Hangar Door Position Open/Close - Two measurements are required to determine if the hangar is opened or closed. One test point indicates an open status; the other a closed status.

The status of the test points identified in Table 6-3 are displayed on the display console.

The information processing routine accesses the data base to determine the positions of the docking ring, the docking port cover, the hatches, and hangar door. This information is displayed at the console which requires execution of the program.

Table 6-3. Operational Status Test Points

FUNCTIONAL AREA	STATUS TEST POINTS
DOCKING MECHANISM	DOCKING RING POSITION DOCKING PORT COVER POSITION
SPACECRAFT ACCESS	HATCH POSITION HANGER DOOR POSITION

6.2.2.3 Docking Mechanism Checkout

The periodic and fault isolation test requirements for the docking mechanism are identical. This routine is executed to assure the operational status of the docking mechanism.

The primary inputs for this function consist of the subsystem test point data.

Specific test points are:

- Docking Port Seal Pressure - The two analog pressures associated with docking port seals are examined to assure that they are within established limits.
- Docking Port Cover Position - This binary test point is used to determine the position of the docking port cover (open/closed).
- Docking Port Cover Control - This test point is used to command the docking port cover to the open or closed position.
- Docking Ring Pressure Control - This test point is used to extend or retract the docking ring.
- Docking Ring Position Extended/Retracted - There are two test points for each docking port. One signal indicates an extended position while the other signal indicates that the docking ring is retracted.
- Docking Ring Strut Pressure - When the docking ring is extended, this test point is examined to determine whether the strut pressure is within limits.

Additional inputs are received as a result of the operator's response to the GO-NO GO options.

An output descriptive message relative to test points, which indicates an apparent error condition, is presented on the display console. When possible, the associated LRU is also identified.

The information processing routine uses a subroutine to check the docking seal pressure at each docking port. The program then attempts to allocate a docking port to prevent altering one of the mechanisms which may be functioning in an operational status. The program then extends and retracts the docking port ring. Each ring is left in its initial position. All position information which is obtained from test points is checked by comparison with the current status being maintained in the data base. For each error that is detected, a failure is indicated for the component, and the operator is presented with an appropriate display.

6.2.2.4 Spacecraft Access Control

This function is used to check the operational status of the spacecraft hatches and hangar door, for both fault isolation and periodic testing requirements.

The inputs for this function consist of the subsystem test point data. Specific test points are:

- Hangar Door Position Open/Close - There are two points for the hangar door. One indicates the open position; the other a closed status.

- Hangar Door Control - This stimuli is used to open and close the hangar door.

- Hangar Pressure - There are two stimuli points for the measurement of the pressure inside the hangar.

- Hangar Temperature - There are two analog points available to measure the temperature inside the hangar.

- Hatch Position Open/Close - There are two stimuli for each of the 16 hatches. One signal indicates the open position; while the other indicates the closed position.

An output descriptive message relative to test points which indicate an apparent error condition are presented on the display console. When possible, the associated LRU is also identified.

In order to efficiently achieve the requirements for both periodic testing and fault isolation for the spacecraft access components, the two were combined into one module and execution is at the operator's option.

The program assures that both test points which provide hangar door positions are in agreement with each other, and with the status being maintained by the DMS. If disagreement is detected, the operator is provided with an appropriate display. When the points and status are in agreement, the hangar door is moved through both the open and closed positions; and the test points and DMS are again examined for consistency. The operator is notified by a display if the door fails to operate, or the positional indicators provide conflicting information.

Subsequent to verifying the hangar door operation if the fault isolation option has been selected, the temperature and pressure in the hangar are limit checked. In the event of a failure, the hangar is configured non-operational and the operator is notified by a display.

The test points which indicate hatch positions are compared against each other and with the DMS status to assure compatibility. In the event of a discrepancy, the hatch will be configured non-operational and the operator is notified by a display.

For each error that is detected, a failure is indicated for the component; and the operator is presented with the appropriate display.

6.2.2.5 Antenna Fault Isolation

The program requires the capacity to analyze the antenna system for purposes of fault isolation.

The inputs for this function consist of the subsystem test point data. Specific test points are:

- Boom Position - This point is used to determine if the antenna is stowed, extended, or retracted for maintenance.
- Launch Storage Position Lock Status - This test point is used to determine the lock position when the antenna is stowed.
- Antenna Launch Stowage Lock Control - This test point is used to assure that the stowage lock can be locked and unlocked to permit deployment of the antenna.
- Boom Deployment Position Lock Status - This test point is used to determine the boom lock status when the boom is extended.
- Boom Deployment Lock Control - This test point is used to assure that the boom locks can be locked and unlocked when the boom is extended.
- Boom Maintenance Position Lock Status - This test point is used to determine the boom lock status when the boom is in the maintenance position.
- Boom Maintenance Position Lock Control - This test point is used to lock and unlock the boom while it is in a maintenance position.

- Drive Unit Power Monitor - This test point is used to be sure that the power monitor is operating within limits.

- Drive Unit Control - This test point is used to issue a test level to the drive unit power monitor, which is then limit checked.

An output descriptive message relative to test points which indicate an apparent error condition are presented on the display console. When possible, the associated LRU is also identified.

The information processing program module performs fault isolation for each antenna. The boom position is read from the specified test point and compared with the current position being maintained by the Data Management System, to insure compatibility. The antenna is in a stowed, extended, or maintenance position. The lock, which is associated with that position, is then checked and again compared with the Data Management System's records for it. If everything is in agreement, the lock is unlocked and relocked to be sure of its operational capacity.

Any discrepancy between positions or failure to lock or unlock results in a message being provided to the operator.

The drive unit power monitor is then limit checked as the final part of this module operation.

For each error which is detected, a failure is indicated for the component; and the operator is presented with the appropriate display.

6.2.2.6 Isotope/Brayton Power Handling Module

This program module is required to check the Isotope/Brayton power supply for purposes of fault isolation. The inputs for this function are the test point values for the power. A descriptive message relative to the power test point is presented on the display console when an error is indicated. The information processing module performs fault isolation by limit checking the drive unit power monitor for the Isotope/Brayton power supply.

6.2.2.7 Artificial "G" Checkout Module

This program module is used to check out the considerations in the structures for the artificial "G" environment. It is anticipated that it will be executed prior to both spin up and spin down activities.

The inputs for this function consist of the subsystem test point data. Specific test points are:

- Spoke Pressure Supply - This test point is used to assure that the pressure supply for the spoke is within limits.

- Spoke Internal Pressure - This test point is used to assure that the internal pressure within the spoke is within limits.

- De-spin Module Rotation Control - This test point is used to place the de-spin module in rotation.

- De-spin Module Rate - This test point is used to measure the rate of the de-spin module's rotation.

- De-spin Module Power - This test point is used to assure that the power being supplied to the de-spin module is within limits.

- S-II Stage Latches Latched/Unlatched - Two test points are used to ascertain the status of the S-II stage latches.

- Cable Deployment Module Strut Ring Position - This test point is used to determine the strut position. In a zero "G" environment, it should be retracted. In an artificial "G" environment, it should be extended.

- Cable Deployment Module Power Monitor - This test point is examined to be sure that the module power monitor is within limits.

An output descriptive message relative to test points, which indicate an apparent error condition, is presented on the display console. When possible, the associated LRU is also identified.

The information processing program module is used to accomplish periodic checkout and fault isolation of those components associated with the artificial "G" environment. The internal pressure supply for the spoke and the internal pressure in the spoke are tolerance checked to assure the habitability for the crew in the spoke. The program then limit checks the power to the de-spin module to assure it is within limits. A de-spin module rotational command is issued to the de-spin module. This command is based upon access to operational data which provides the spin rate of the space station. Using this data, rates are computed which the module is expected to attain. The de-spin module rate is evaluated at one second intervals for a sample period and compared to the precalculated limits.

Status checks are then made on the cable deployment module. The S-II latch positions are status checked; and in the event of a positional discrepancy, the display reflecting the S-II latch positions is presented. The strut position is then status checked to assure that it is in the proper position for the current environment.

6.2.2.8 Termination Routine

This module is included to assure the orderly return of control to the executive at the completion of execution.

The inputs to this module indicate a successful or unsuccessful completion of program execution. In the event termination is required due to operator intervention, or a detected failure, additional inputs as to the status of the associated components are required.

information processing must accomplish the functions required to assure the subsystem is properly configured before control is returned to the executive.

Upon entry, this module determines if the program has been terminated as a result of operator intervention or successful completion of the test.

In the event of operator intervention, the bookkeeping required to assure that the subsystem is properly configured must be accomplished.

A message indicating completion of execution is presented, and control is returned to the executive.

6.2.3 INTERFACE REQUIREMENTS

This program requires interface with the master executive, OCS executive, and the structure subsystem hardware.

The interface between the Structure Subsystem checkout program and the executive architecture is shown in Table 6-4.

Detailed interfaces which are required in the executive architecture to service this program are defined in paragraph 3. 2. 2 of Appendix A of the Task 2 Final Report.

Table 6-4. Structures Checkout Program and Executive Program

	EXECUTIVE PROGRAM															
STRUCTURES C/O PGM	Task Specification	Processor Allocation	Task Termination	Memory Allocation	Peripheral Allocation	Data Base Allocation	Interrupt Monitoring	Failure Response	Output Processor	Input Processor	Special Processor	Data Retention	GO-NOGO Processor			
Option Control									x	x						
Operational Status									x		x		x			
Docking Mechanism									x		x		x			
Spacecraft Access									x	x	x		x			
Antenna Deployment									x		x		x			
I/B Power Handling									x		x		x			
Artificial "G" C/O									x		x		x			
Termination			x						x							

Section 7

MAINTENANCE

There are two aspects of maintenance which entered into the basic study. Basic maintenance concepts were provided as part of the baseline resulting from the Phase B Space Station study; they are discussed in subsection 7.1 below. Additionally, one of the study tasks was aimed at implementation of an onboard electronics maintenance capability. The results of that task are summarized in subsection 7.2.

7.1 BASELINE MAINTENANCE CONCEPTS

Maintenance concepts defined for Space Station subsystems are intended to facilitate their preservation or restoration to an operational state with a minimum of time, skill, and resources within the planned environment.

7.1.1 GENERAL SPACE STATION MAINTENANCE POLICY

It is a Space Station objective that all elements be designed for a complete replacement maintenance capability unless maintainability design significantly decreases program or system reliability. This objective applies to all subsystems wherever it is reasonable to anticipate that an accident, wearout, or other failure phenomenon will significantly degrade a required function. Estimates of mean-time-between-failure, or accident/failure probability, are not accepted as prima facie evidence to eliminate a particular requirement for maintenance. Should the accident/failure probability be finite, the hardware is to be designed for replacement if it is reasonable and practical to do so.

As a design objective, no routine or planned maintenance shall require use of a pressure suit [either EVA or internal vehicular activity (IVA)] . Where manual operations in a shirtsleeve environment are impractical, remote control means of affecting such maintenance or repairs should be examined. However, EVA (or pressure suit IVA) is allowable where no other solution is reasonable, such as maintenance of external equipment.

Time dependency shall be eliminated as a factor of emergency action insofar as it is reasonable and practical to do so. This includes all program aspects of equipment, operations, and procedures which influence crew actions. When time cannot be eliminated as a factor of emergency action, a crew convenience period of 5 minutes is established as the minimum objective. The purpose of the convenience period is to provide sufficient time for deliberate, prudent, and unhurried action.

7.1.2 ONBOARD MAINTENANCE FACILITY CONCEPTS

In addition to OCS/DMS capabilities, other onboard maintenance support facilities provided on the Space Station include:

- Special tools for mission-survival contingency repairs such as soldering, metal cutting, and drilling, as determined from contingency maintenance analyses, although repairs of this type are not considered routine maintenance methods.

- Protective clothing or protective work areas for planned hazardous maintenance tasks (such as those involving fuels, etc.).

- Automated maintenance procedures and stock location data for both scheduled and unscheduled maintenance and repair activities.

- Real-time ground communication of the detailed procedures, update data, and procedures not carried onboard.

- Onboard cleanroom-type conditions by "glove box" facilities compatible with the level at which this capability is found to be required.

- Maintenance support stockrooms or stowage facilities for spares located in an area that provides for ease of inventory control and ready accessibility to docking locations or transfer passages.

7.1.3 SUBSYSTEM MAINTENANCE CONCEPTS

Space Station subsystems utilize modular concepts in design and emplacement of subsystem elements. Subsystem modularity enhances man's ability to maintain, repair, and replace elements of subsystems in orbit. Providing an effective onboard repair capability is essential in supporting the Space Station's ten-year life span since complete reliance on redundancy to achieve the long life is not feasible. The need for a repair capability, in turn, requires that a malfunction be isolated to at least its in-place remove-and-replace level. The level of fault isolation is keyed to the LRU, which is the smallest modular unit suitable for replacement. The identification of subsystem LRUs is addressed as a separate, but interdependent, part of the Onboard Checkout Study.

Specific subsystem maintenance concepts, of course, depend upon examination of the subsystems. These concepts are discussed in subsequent subparagraphs. General subsystem-related maintenance guidelines that have been established for the Space Station are:

- It is an objective to design so that EVA is not required. However, EVA may be used to accomplish maintenance/repair when no other solution is reasonable.

- Subsystems will be repaired in an in-place configuration at a level that is acceptable for safety and handling, and that can be fault-isolated and reverified by the integrated OCS/DMS. This level of maintenance is referred to as line maintenance and the module replaced to effect the repair is the LRU.

- A limited bench-level fault isolation capability will be provided on the Space Station, but is only intended for contingency (recovery of lost essential functions beyond the planned spares level) or for development purposes. Limited bench-level support is also provided in the form of standard measurement capabilities which are used primarily to reduce the amount of special test equipment required.

- Subsystem elements, wherever practical, will be replaced only at failure or wearout. Limited-life items that fail with time in a manner that can be defined by analysis and test will be allowed to operate until they have reached a predetermined level of deteriorated performance prior to replacement. Where subsystem downtimes for replacement or repair exceed desirable downtimes, the subsystem will include backup (redundant) operational capability to permit maintenance. Expendable items (filters, etc.) will be replaced on a preplanned, scheduled basis.

7.2 ONBOARD ELECTRONIC MAINTENANCE (STUDY TASK 3)

The objective of this task was to generate recommendations of supporting research and technology activities leading to implementation of a manned electronics maintenance facility for the Space Station. Early in the task it became apparent that attention could not be confined to a central maintenance facility; it was necessary to refocus the task to address implementation of an on-board maintenance capability encompassing in-place as well as centralized maintenance activities. The critical questions are the following:

- What is the optimum allocation of onboard maintenance functions between in-place and centralized maintenance facility locations?

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- What is the optimum level of onboard repair (i.e., to line-replaceable unit, subassembly or module, piece part, or circuit element)?

7.2.1 MAINTENANCE CYCLE

In order to place the task in the proper context, a generalized Space Station electronic maintenance cycle is depicted in Figure 7-1.

A convenient place to enter the cycle is with detection of a fault ("In-Place Maintenance" block). The fault is isolated to a Line Replaceable Unit (LRU). The affected subsystem is restored to full capability by replacing the failed LRU with an operable one from spares storage.

The failed LRU is taken to a maintenance facility (assumed for the moment to have a fixed location in the Space Station) where it is first classified as repairable or non-repairable. Classifications will likely be predetermined, and a listing should be retained in the Data Management Subsystem. If the LRU is non-repairable, it is placed in segregated storage. If the LRU is repairable on board, the fault is further isolated to the failed Shop Replaceable Assembly (SRA). The LRU is then repaired by replacing the failed SRA with one from spares storage. The repaired LRU is then calibrated (if necessary), and its operation verified before it is placed in spares storage.

Logistics requirements (replacement LRUs and SRAs needed) are transmitted to ground-based logistics support functions by RF communications and/or Space Shuttle. Failed units are taken away from and replacement units are delivered to the Space Station by the Space Shuttle.

7.2.2 SUMMARY OF RESULTS

The study confirmed and emphasized the necessity of onboard maintenance for any manned mission of any complexity and duration measured in months (up to 10 years for Space Station). Formulation of recommendations for implementing such a capability required consideration of other topics first, and achievement of certain interim results. The principal conclusions of this study task are summarized below. The analyses leading to them are explained in the Task 3 Final Report.

- Prior studies and developments of in-space maintenance have emphasized justification of first-level (in-place) maintenance, fasteners, and tools for space application and human factors criteria. Much less attention has been devoted to test equipment, maintenance training, or definition of shop level maintenance requirements.

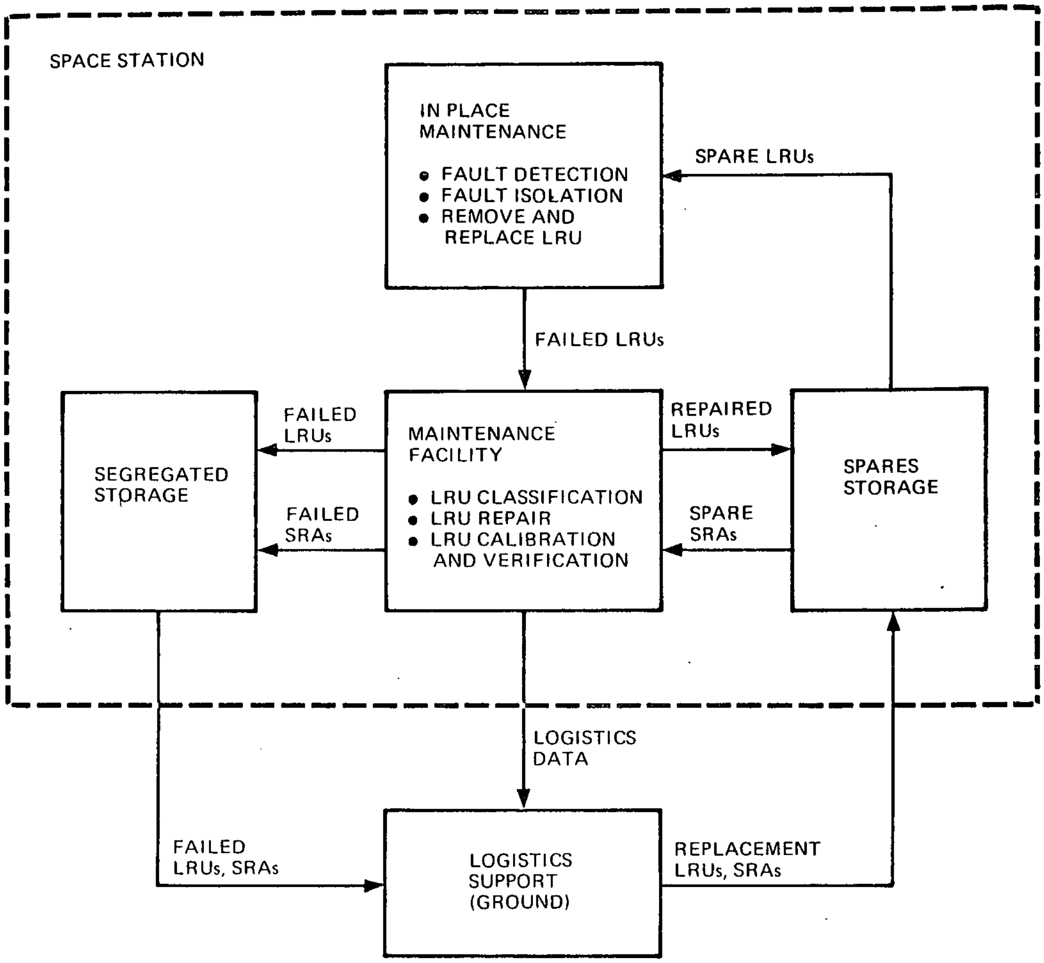

Figure 7-1. Space Station Maintenance Cycle

- The baseline subsystem descriptions, checkout requirements analysis, and software requirements analysis indicate that approximately 60 percent of all faults (over a long period) can be isolated to the failed LRU automatically under software control, without crew intervention. In an additional 27 percent of failure cases, fault isolation to one LRU can be achieved by the crew using the onboard Data Management System as a tool. In the remaining failure cases, additional fault isolation capabilities are needed. This is a good result for a "first iteration" and can probably be improved considerably with a modest effort to modify stimulus and measurement provisions.

- Crew involvement in scheduled and unscheduled maintenance (including participation in fault isolation) is estimated to average 7.2 manhours per week over the total mission time. This estimate is most sensitive to equipment reliability and levels at which onboard repair is performed. It is affected little by the efficiency of automated fault isolation under control of the Data Management Subsystem (DMS).

- The recommended approach to maintenance in the baseline Space Station is in-place removal and replacement of LRUs, without attempts to repair LRUs onboard, if the resupply interval is less than nine months. Onboard spares should be LRUs.

- For long resupply intervals or non-resupplied missions (as in a manned interplanetary mission), in-place maintenance should be by removal and replacement of LRUs. Repair of LRUs should be by removal and replacement of Shop Replaceable Assemblies (SRAs). Onboard spares should be SRAs.

- The Earth-orbital Space Station should include provision for development of onboard maintenance capability and techniques applicable to long duration non-resupplied missions and/or the larger, more complex Space Base.

- The baseline subsystem descriptions are at such a level of detail that precise specification of onboard tools and test equipment is neither feasible nor desirable. Anticipated needs identified qualitatively in the study are: (1) a portable test module to supplement software fault isolation as well as to assist mechanical adjustments and calibrator, (2) hand tools for removal and replacement of electronic assemblies, (3) devices for transporting and positioning spare assemblies, and (4) a central maintenance/repair bench.

- Several tasks have been identified and recommended for future performance, as part of a system study/design program or as separate supporting research and technology tasks. The principal ones deal with (1) development of a portable test assembly, (2) development of a repair/test bench with special provisions for small parts retention and for debris collection, (3) design for accessibility of test points and subassemblies, and (4) devices for transporting equipment within the Space Station.

The foregoing conclusions apply to the Modular Space Station as well as the 33-foot diameter, four-deck configuration.

The results of the study rest upon several assumptions and estimates, derived wherever possible from related experience. The results are not sensitive to small variations of the assumed or estimated values, except for equipment failure rates, which are most influential. Furthermore, it has not been practicable to pursue all trade analyses to include all relevant factors. Nevertheless, the study has generated valid insights into Space Station onboard maintenance and useful visibility of the path to implementation of that capability.